INNOVATION AND DEVELOPMENT OF A HIGH PRESSURE WATER NOZZLE DISCHARGED WITH CURTAIN SPRAY FOR OIL LEAKAGE IN OFFSHORE

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ABSTRACT

This study deals with the development of high pressurized water nozzle using dispersion method for oil leakage in offshore. The objectives of this project are to design a new spray nozzle using theoretical data and comparison with already existed nozzle, AFEDO nozzle. The nozzle is design with 5 degree reduction and 3 discharged holes of 0.5 cm in diameter. Computational study of the flow was done by using ANSYS CFX to study the distribution of the flow. Experiment was done at PIMMAG PD Base in Port Dickson, Negeri Sembilan with pressure of 80 psi / 5.5 bar. Results obtain from both analyses show a significant spray pattern and flow distribution as well as distance.

ABSTRAK

Pembelajaraniniberurusandengankajiantentangpembangunannozeltekanantinggimenggunakankaedahpenyebaransemburan air untuktumpahanminyak di laut.Objektifprojekiniadalahuntukmerekanozelsemburan yang barumenggunakan data secarateoridanpembandingandengannozelsediaadiaitu AFEDO nozel.Nozel yang barudirekadengan 5 darjahkurangdan 3lubang pancutaniaitu 0.5 cm dalamukurlilitbulatan.Pembelajarantentangpengiraanalirandilakukandenganmenggunakanperisian ANSYS CFX danjugabelajartentangpengagihanaliran.Eksperimentelahdilakukan di PIMMAG PD Base di Port Dickson, Negeri Sembilan dengantekananiaitu 80 psi / 5.5 bar.Keputusandaripadakedua-duaanalisismenunjukkankepentingancorakpancutandanpembahagianaliranbegitujugajarakpancutan.

TABLE OF CONTENTS

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ρ	Fluid density
t	Time
u	Initial flow velocity
v	Final flow velocity
k	Constant
μ	Viscosity
P	Pressure
ε	Surface roughness / Turbulent dissipation rate
S	Strain tensor
A	Area
V_1	Initial velocity
V_2	Final velocity
d	Diameter
Q	Flowrate

LIST OF ABBREVIATIONS

CFD	Computational fluid dynamics
KE	K epsilon
PD	Port Dickson
PIMMAG	Petroleum Industry of Malaysia Mutual Aid Group

CHAPTER 1

INTRODUCTION AND GENERAL INFORMATION

1.1 PROJECT BACKGROUND

In the oil and gas industry, oil spill incident is very hard to avoid even all the precaution and safety already implemented. Therefore the company which are acted as the Oil Spill Response (OSR), working hard in order to find a perfect solution to recover the nature from the oil spill which will affect the ecosystem either at the sea, river, pond and land.

Through this, there are so many inventions that is produced by production company either they are related to oil and gas industry or not. The idea came from the OSR Company. Examples of OSR equipment that is produced then are, boom which is used to encircle the spill oil so that they are not spreading, skimmer that act as a vacuum which is used to suck the spill oil, adsorbent boom which are able to absorb spill oil only and the great invention is AFEDO™ nozzle. But then, this nozzle is not able to suck or absorb the spill oil. The main use of this nozzle is to spray dispersant.

Dispersants are mixtures of solvents, surfactants, and other additives that are applied to oil slicks to reduce the oil-water interfacial tension. Dispersants can be applied to spilled oil on open water by boats or aircraft. Vessel spraying Dispersants are usually applied from boats equipped with spray arms. In typical spray arm system, diesel engine is used to pump dispersants from a storage tank through a set of nozzles calibrated to produce a uniform spray pattern of droplets. If spray arms are not available, AFEDO^{TM} is used to apply diluted concentrate dispersants.

The AFEDO^{TM} nozzles have been designed to create an even drop-out spray, such that the volume/mass of droplets falling along the spray pattern is evenly distributed. This effect replicates the spray pattern produced by spray arms. The main objective of this invention is to replace spray arm which is heavy and difficult to install. By using this AFEDO^{TM} nozzle, it is portable and easy to install.

1.2 PROBLEM STATEMENT

Water projection and the spray pattern which related to this application depend on the geometry of the injector nozzle comprising spray holes and the diameter. Spray nozzles are carefully engineered to deliver specific performance under certain operating conditions. Their performance is affected by the nozzle type, spray pattern, capacity, operating pressure, material of construction, water droplet and spray distribution, angle and impact. In order to design this project, these nine parameters must be analyzed to produce the optimum nozzle injector.

Therefore, for this application, the thing that must be considered is the interior design of the nozzle whether does it affect the distance of water projection or not. Then, in order to create an even drop-out spray, it is possible to decrease the arcs and the discharge holes which the existence product, there are four arcs and four discharge holes.

So that, studies on the design, the spray characterization and the basic physical mechanisms involved in the formation of spray have to be carried out while the application is considered.

1.3 OBJECTIVES OF THE PROJECT

The overall aim of this project is to innovate and develop a new high pressure water nozzle with curtain spray projection to replace AFEDO^{TM} nozzle. Therefore, the main objectives of this project is to design a new nozzle with the dimensions are the same as the existence product which is AFEDO^{TM} nozzle but there is slightly modification in the interior part of the nozzle in order to produce high velocity of water flow which contribute to further distance of water discharged. In addition, of course to create even drop-out spray characteristic such that the volume/mass of droplets falling along the spray pattern (curtain spray) is evenly distributed.

1.4 SCOPES OF THE PROJECT

The scopes of this project which mean the parameters that have to be considered in order to make this project success are:

1) Boundary condition:
   Material used for this project is mild steel and aluminum
2) Four parameters which are:
   - Pressure by the power pack – 80psi = 5.5bar
   - Fluid source – water, d = 1000 kg m^{-3}
   - Flow rate, v – 100 l s^{-1} to 120 l s^{-1}
3) Simulation by using software (ANSYS)
   - Initial condition – steady state (v = 100 l s^{-1} to 120 l s^{-1})
   - Flow velocity at inlet – 5 m s^{-1}
   - Pressure at outlet – 0 kpa
   - Adiabatic flow and no heat transfer
4) Fabrication process
5) Testing performance by experiment setup

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The literature review had been carry out with reference from sources such as journal, books, thesis and internet in order to gather all information related to the title of this project. This chapter covers about the previous experiment doing by researcher and to go through the result by experimental and numerical.

2.1.1 History of AFEDO^{TM} Nozzle

AFEDO^{TM} nozzle has been specially developed by AylesFernie to meet a requirement for application systems of dispersant which will not require multiple nozzle spray arms from tugs boat in **Figure 2.2**, offshore supply vessel and workboats. The nozzles create an even drop-out spray plume about 10m to 15m on either side of the vessel and are easily installed with a universal clamping device that can be secured to any convenient vessel structure as show in **Figure 2.1**. Only two nozzles per vessel are needed for port and starboard dispersant application.

Not having to install and deploy side spray booms makes dispersant spraying a much simpler operation. Spraying systems employing this nozzle are both light and compact, easily moved from vessel to vessel without the need for traditional fittings and modifications.

Figure 2.1: AFEDO^{TM} nozzle

Figure 2.2: Arm Spray

Source: http://www.nauticexpo.com/prod/ayles-fernie-international/oil-spill-dispersant-spray-systems-nozzles-type-boat-mounted-32632-199703.html

2.1.2 Working Principle of AFEDO^{TM} Nozzle

AFEDO Nozzles have been designed to create an even drop-out spray characteristic such that the volume and mass of droplets falling along the spray pattern is evenly distributed. This effect replicates the spray pattern produced by spray arms.**Figure 2.3** and **Figure 2.4** show the water discharged from AFEDO^{TM} Nozzle and Spray Arm.

Figure 2.3: Water projected from AFEDO^{TM} Nozzle

Figure 2.4: Water injected from Spray Arm

Source: Pictures taken at PIMMAG PD Base

High injection pressures combined with small nozzle hole diameters can provide better spray formation, better air entrainment, better air-fuel mixing, and more homogeneous mixture with lower equivalence ratio and fewer over-rich regions. Therefore, in this study, the smaller the water the droplet, the better the spray formation needed.

2.2 DESIGN CONSIDERATION

In this study, design consideration is the viral factor that should be stressed on. This is because, design factor is the most important part which, it is used to illustrate the virtual design to actual design. In fact, by looking to the design, roughly it will estimate the result in the future without doing any experiment. Design is not just what it looks like and feels like, design is how it works (Steve Job, 2010).

2.2.1 Interior Design

Generally, in order to generate high velocity of fluid injected, the nozzle must be convergent which mean, narrowing down from a wide diameter to a smaller diameter in the direction of the flow. Convergent nozzles accelerate subsonic fluids. If the nozzle pressure ratio is high enough the flow will reach sonic velocity at the narrowest point which is at the nozzle throat. In this situation, the nozzle is said to be choked.

Based on the journal of Nozzle design influence on particle attrition by a supersonic steam jet, (Pougatch, Salcudean, & McMillan, 2011). They are investigating the perfect outlet diameter in order to produce high velocity of fluid injected and the pecfect discharge hole either under-expanded jet or perfectly-expanded jet or over-expanded jet as shows in the **Figure 2.5**.

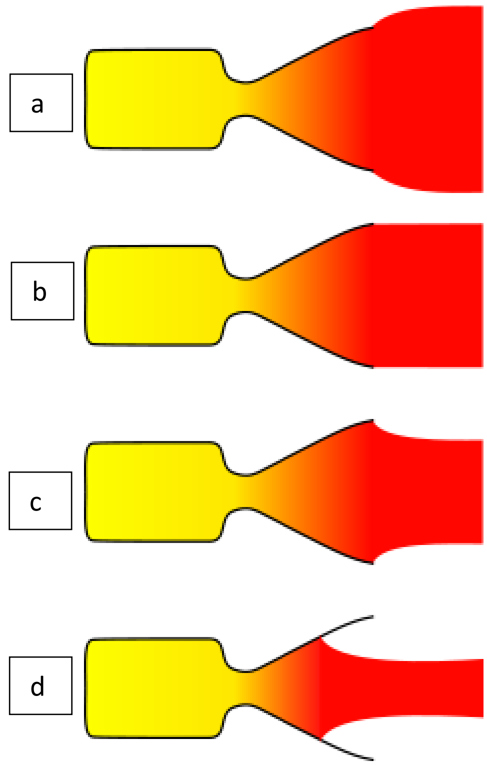

Figure 2.5: (a) Under-expanded (b) Perfectly-expanded (c) Over-expanded (d) Grossly over-expanded

Source: http://en.wikipedia.org/wiki/Rocket_engine_nozzle

After the experiment, the perfectly-expanded jet produce in the largest penetration distance compared to others. That is mean, the discharge hole must be ideal with the whole dimensions of nozzle.

2.2.2 Nozzle Expansion Angle

Besides the interior design and the discharge hole, angle also playing the important role in order to increase the distance fluid injected. The perfect angle would give the optimum distance of fluid injected by the nozzle. Therefore, the journal by Pougatch, Salcudean, & McMillan, (2011), for attrition process, the smaller the angle, the better the attrition. It is proven by the graph, (Pougatch et al., 2011) in the **Figure 2.6**.

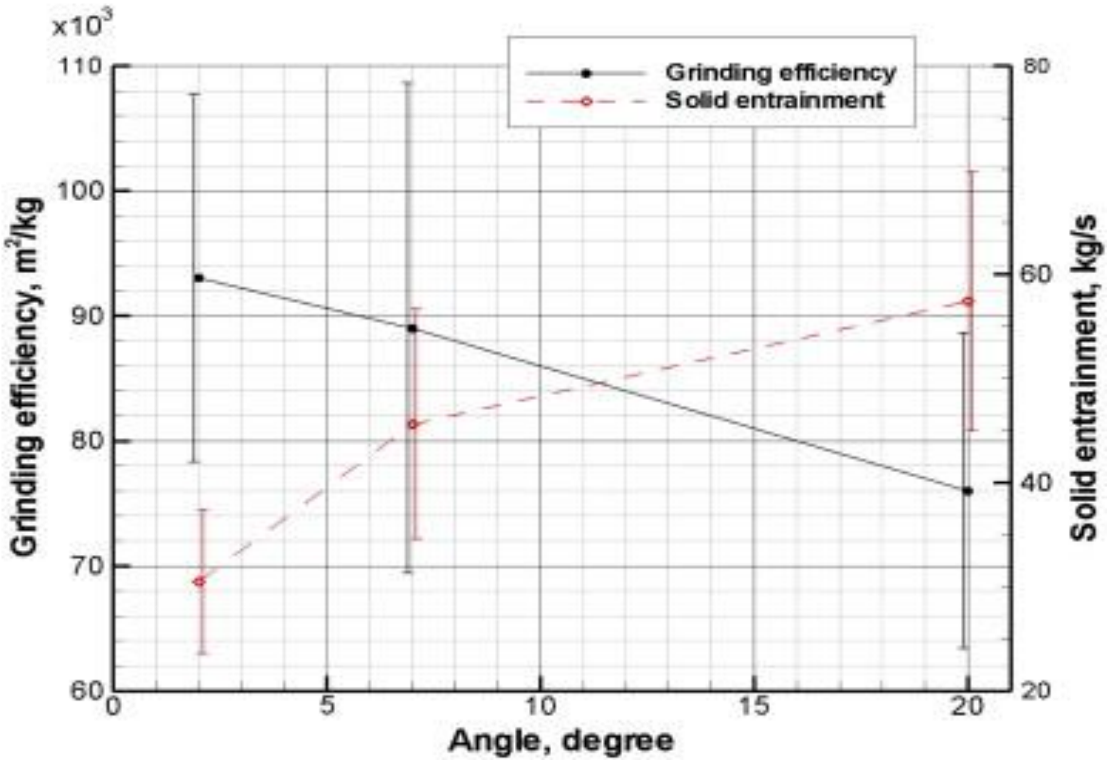

Figure 2.6: Graph of grinding efficiency and solid entrainment variation with expansion angle

Source: http://www.sciencedirect.com/science/article/pii/S003259101100043X

The graph in the **Figure 2.6**, shows that the smaller the angle would produced greater grinding efficiency. This mean that, the angle is an important parameter that would give the optimum result.

2.3 CURTAIN SPRAY

Instead of improvise the distance of injected fluid, the important criteria is the spray pattern along the distance is like curtain. Figure 2.7 shows the curtain spray pattern by AFEDO^{TM} Nozzle. Based on the picture, the spray pattern is look alike the curtain pattern and along the spray injected (14-15m), water droplet is falling like it is raining.

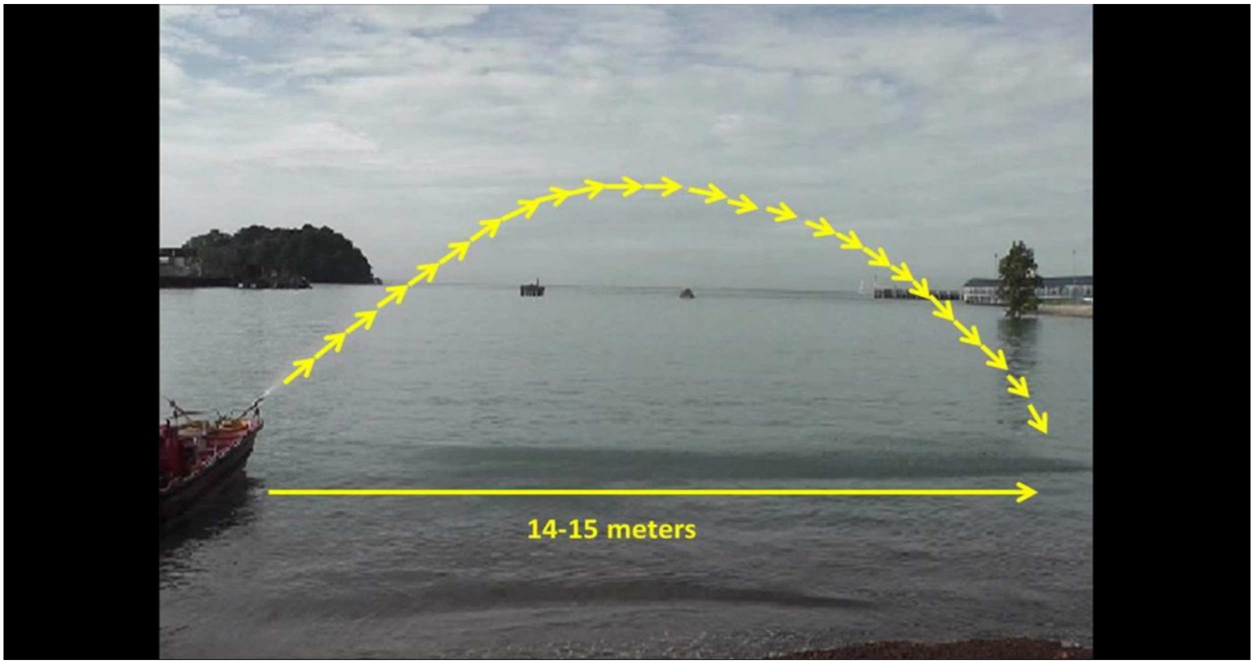

Figure 2.7: Curtain spray pattern

Source: AFEDO^{TM} Nozzle demonstration video

Therefore, in this subchapter and the following one, a review of the literature to provide background about the sprays pattern.

2.3.1 Atomization process

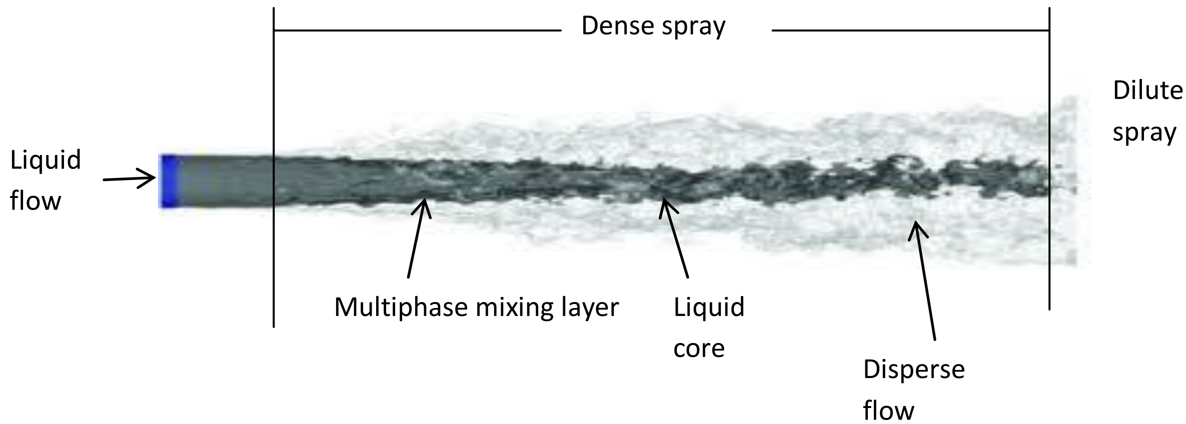

Figure 2.8: Pressure-atomised spray near the nozzle tip

Source: http://www.cd-adapco.com/news/2009/03-17-atomic.html

In the most basic sense, a spray is simply the introduction of liquid into a gaseous environment through a nozzle such that the liquid, through its interaction with the surrounding gas and by its own instability, breaks-up into droplets. The formation of a spray begins with the detaching of droplets from the outer surface of a continuous liquid core extending from the orifice of the injection nozzle as shown in the **Figure 2.8**.

The process of atomization is one in which liquid is disintegrated into drops and ligaments by the action of internal and external forces which it leads to the spray formation. It proceeds more easily if the liquid is present in a form that is more susceptible to disintegration: thin jets or liquid sheets, because they have the highest surface energy and thus the greatest instability.

The atomization process depends mainly on the injection velocity in the nozzle hole. The spray cannot be formed correctly (incomplete spray) for low injection velocities, causing an insufficient atomization, with a long transformation process from liquid column to droplets. However, when cavitation (complete spray) is initiated in the injection holes, by increasing the injection velocity, dramatic changes occur in the spray structure. A rapid disintegration process from jet to fine spray appears.

2.3.2 Effect of injection pressure and nozzle shape on atomization

As previously mentioned, high injection pressures combined with small nozzle hole diameters can provide better spray formation, better air entrainment, better air-fuel mixing, and more homogeneous mixture with lower equivalence ratio and fewer over-rich regions. In addition, there are other ways to improve the spray atomization, such as improvement of the nozzle configuration. Nozzle configuration has an important effect on the fuel atomization. The configuration includes the following factors which are the surface area of the nozzle hole, the entrance shape of the hole, the number of holes, the length to diameter ratio, the orientation of the nozzle holes with respect to the nozzle axis and the sac volume.

The authors used a mini-sac injector with two types of nozzle hole entrances, sharp-edged and round-edged inlet. Higher injection pressures resulted in longer spray tip penetrations, narrower spray angles and smaller particle sizes for both nozzle entrance shapes. The sharp edged inlet nozzle produced a wider spray dispersion angle, smaller SMD and a smaller value of particulate emission, compared to the round-edged inlet tip. Atomization can also be improved by increasing the fuel flow velocity in the nozzle hole.

2.4 COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS

2.4.1 Definition

Fluid, that consists of gas and liquid, flows are governed by partial differential equations which represent conservation laws for the mass, momentum, and energy. Computational fluid dynamics (CFD) generally being defined as the method that provides a qualitative, and sometimes quantitative prediction of fluid flows by using mathematical modelling, numerical methods, and software tools. The mathematical modelling consists of partial differential equations, while numerical method consists of discretization and solution techniques, and software tools consists of solvers, pre-processing, and post-processing utilities. The main advantage of the computational fluid dynamics analysis is that it reducing the efforts in determining the fluid flow and reducing costs required for experimentation.

2.4.2 The Computational Fluid Dynamics (CFD) Components

The components of the computational fluid dynamics play an important role in determining the prediction of the fluid flows. The components consist of human being, scientific knowledge, computer software, and computer hardware.

The context of the human being refers to the function of the analyst as the person who identify and states the problem that needs to be solved. For example, before starting the analysis, the analyst should know the goal or objective of the analysis, as the goal maybe the maximum temperature separation of the vortex tube. Another role of the human being is that as the analyst, in the end of the analysis, by referring to the simulation made, the analyst should be able to inspects and interprets the the simulation results. By this means, the analyst should be able to compare with the present experimental result.

In determining the prediction of the fluid flows, the scientific knowledge must be applied to the fluid flow behaviour. By this means, the scientific knowledge refers to the determination of which turbulence models that appropriate to be used, and which method is the most practical. The computer code, or the computer software, which applies this knowledge and provides detailed algorithm instructions. The final computational fluid dynamics component is the computer hardware which performs the actual calculations of the analysis. The computational fluid dynamics analysis is a highly interdisciplinary